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Editorial

This first edition of the REAAA Journal for 2005 contains five Papers and one Technical Note.

The first paper, "Analysis and Simulation of Kuala Lumpur City Bus Lane System" describes an evaluation, using simulation, of the effectiveness of the Kuala Lumpur City bus lane system during peak periods in terms of both total travel time and average travel time.

The Korea Highway Corporation Test Road is a major full-scale road-testing facility recently commissioned by the Korea Highway Corporation. The second paper describes the test road, including its construction, the test sections and the results of a pilot study conducted prior to the facility being opened to traffic in March 2004.

The management of the road network to provide safe road transport is a key performance indicator for all road agencies. The third paper describes the development of the Road Safety Risk Manager, its features and its application as a tool to assist road safety managers to demonstrate a responsible approach to managing road safety risk.

The next paper "Concepts of Reliability in Mechanistic-Empirical Bituminous Pavement Design" discusses the issue of the variability involved in the pavement design process and the estimation of the reliability of the design of a pavement derived using the mechanistic-empirical approach. This allows a designer to design a pavement to a given level of reliability, and hence allow a comparison of alternative pavement designs.

The final paper summarises the reasons behind the establishment of the International Centre for Pavement Engineering Education (ICPEE), outlines its development and operation and examines its likely future. The changes occurring in the pavement industry worldwide since the late 1980s have focused the attention of the Centre's founders on the need to provide education and training initiatives at a number of levels. ICPEE was formed to fill a specific void which existed in postgraduate pavement engineering education programs.

Austroads is currently funding a research project to better define the interactions between heavy vehicles and the pavement surface and to optimise the surfacing selection process. A Technical Note discusses some of the issues being addressed in this project.

ARRB Group has recently undergone a major restructure as a result of a recent agreement with Austroads and the development of a technical research program. Some details of the new structure are also included in this issue of the Journal.

The Editorial Panel is actively seeking papers and technical notes for publication in the Journal. There have been some changes to the composition of the Editorial Panel since the most recent issue of the Journal in 2004. Mr Paula Baleilevuka, Ministry of Works & Energy, Fiji, is the new member representing the Pacific Islands whilst Mr Asao Yamakawa of the Japan Bridge Association is the first member of the Panel to represent Japan.

The revised membership of the Editorial Panel follows. REAAA members interested in submitting a paper should seek advice from the appropriate member(s) of the Editorial Panel. The Panel is striving to publish at least one paper from each Chapter or region each year.

Kieran Sharp
Chairman REAAA Technical Committee

MEMBERSHIP OF EDITORIAL PANEL: REAAA JOURNAL - MAY 2005

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ANALYSIS AND SIMULATION OF KUALA LUMPUR CITY BUS LANE SYSTEM

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ABSTRACT

The objective of the study described in this paper was to evaluate, using simulation, the effectiveness of the Kuala Lumpur City bus lane system during peak periods. It was found that, in some cases, the total travel time varied with the speed of travel but that, if buses are travelling at an average travel speed of 40 km/h, then the bus lane is being fully utilised. It was also found that the average travel time was no different for buses travelling at average speeds of 45 and 50 km/h.

Overall, the operation of the bus lane system was found to be effective, with the travel time for buses shortened when they travelled along the bus lane system. Even though there were no relative differences between the total travel time when buses travelled at 40, 45 and 50 km/h, the use of the bus lane system resulted in a decrease in total travel time. This resulted in an increase in the number of trips and a decrease in passenger waiting time.

An increase in the level of enforcement of the road laws to discourage drivers from parking in the bus lane at some locations will result in an increased level of efficiency in usage of the bus lane.

1. INTRODUCTION

Buses provide a versatile form of public transport. They serve a variety of access needs and can operate at an unlimited range of locations throughout a metropolitan area (Guey-Shii et al. 1995). However, in terms of the effective operation of bus systems, traffic congestion is always an issue as it causes delays. The use of a bus lanes system is one way to address this problem.

A bus lane is a lane reserved for the exclusive, or near exclusive, use of buses. The US Highway Capacity Manual (1997) suggests that an exclusive bus lane can be provided when the when the width of the carriageway is sufficient to allow safe operation, i.e. a minimum width of 2.8 m and ideally a width of 3.6 m.

A bus lane system will be successful if it operates over a significant length of road, if an effective enforcement policy is in place to exclude other traffic and if satisfactory signing and lane-marking is provided, including bus detectors at locations where the bus lane crosses other streets. The Highway Capacity Manual has predicted that the provision of an effective bus lane system can result in a 25% reduction in bus travel time and a 15% reduction in accidents involving buses.

1.1 Bus Lane System in Kuala Lumpur City

The Government of Malaysia initially proposed a bus lane system for Kuala Lumpur City in September 1996. It was hoped that the provision of a bus lane system would lead to:

- an improvement in public transport (especially buses) services through a reduction in travel time and the generation of more trips;
- a reduction in congestion as more residents chose to use public transport; and
- an improvement in road user discipline, especially the bus drivers.

The bus lane system in Kuala Lumpur is shared with taxis but no other traffic. It is located on the left side of the road, with its borders marked with continuous yellow lines and the wording "*Bas sahaja*" (Buses only) painted onto the road surface (Perunding Lee dan Rakan et al. 1995). In addition, special signage was placed along the bus lane as shown in Figure 1.

Signboard within 5m of beginning of bus lane system

Signboard at beginning of bus lane system

Signboard along bus lane system

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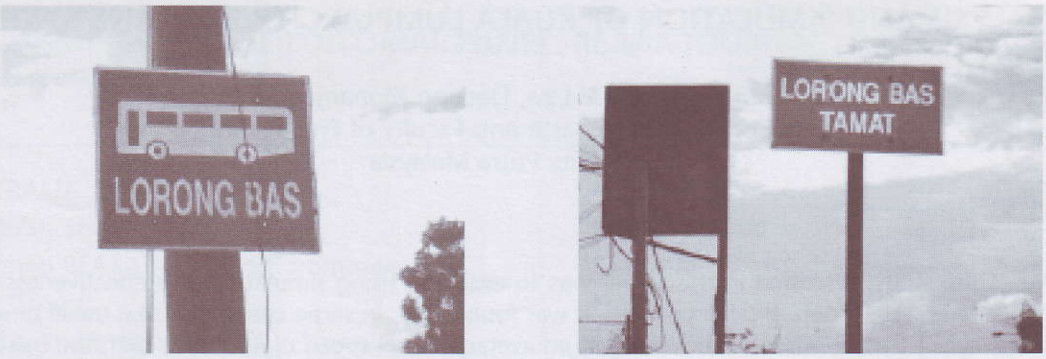


Signboard along bus lane system — Signboard at end of bus lane system

Figure 1: Standard signboards along Kuala Lumpur City bus lane system

The system operates between 6 a.m. and 8 p.m. every day except for Sundays and public holidays. Offenders (anyone other than bus or taxi drivers) are summoned if they travel in the bus lane during its operation. A total of 34 main roads intersect the bus lane system. A typical view of the bus lane in operation is shown in Figure 2. To avoid congestion, the width of the bus lane is equivalent to one and a-half times the width of the lane for normal traffic.

The purpose of the study described in this paper was to evaluate the effectiveness of the Kuala Lumpur City bus lanes system using simulation modelling.

Figure 2: Bus lane in Kuala Lumpur City
(Location: Jalan cheng Lock)

2. SIMULATION MODELLING

Modelling and simulation is an essential element in the design, evaluation and operation of a transportation system. Traffic simulation models may be stochastic or deterministic (Young 1984). The main reason that simulation – which is a descriptive modelling technique – was chosen to analyse the bus lane system in Kuala Lumpur City in preference to other analysis techniques was because the bus lane system is complex and real traffic data was required to analyse the effectiveness of the system. In addition, the volume of vehicles using the system fluctuates over time; peaking during peak hours and this can be handled by simulation models (Young 1984).

Usually, simulation models are developed using appropriate computer and simulation languages depending on the purpose of the model. Whilst simulation model will always produce different results, the results will be distributed around the mean value. There has recently been considerable development in simulation models as sophisticated computer facilities are becoming more available and traffic engineers become more aware of their potential for solving traffic problems.

The simulation model, TRAF-NETSIM, was used to refine and calibrate the factors influencing bus lane speed and capacity, including the number of buses per hour, the number of bus stop per mile, the bus stop dwell time, service patterns, signal constraints, and traffic volume (Kevin and Herbert 1997). The work reported in this paper placed particular emphasis on bus lane operations and procedures for estimating bus speeds along arterial roads using average values for the aggregate traffic delays involved. Low-cost investments in infrastructure, equipment, operational improvements and technology can provide the foundation for a bus rapid transit system that leads to a substantial improvement in bus system performance. Bus traffic signal priority can be implemented effectively in conjunction with dedicated bus lanes (Joseph, Melissa and Judity 1996).

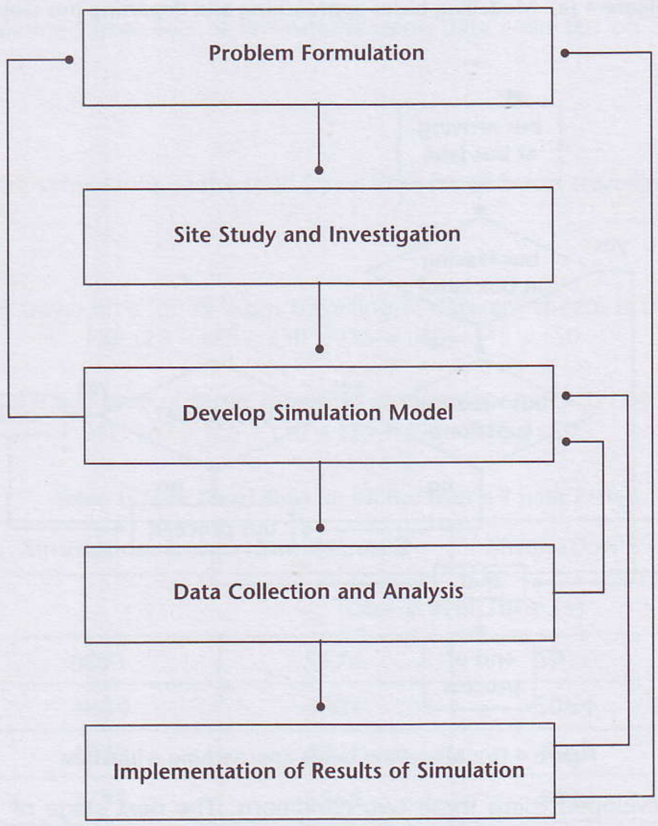
A bus dispatching control model was developed for evaluating and implementing strategies along bus routes. Buses were controlled using two models: dispatch control and signal control. Bus priority control with a minimum feasible cycle was found to be beneficial only for longer bus headway services. Numerical results showed that the average bus delay time could be reduced up to 55 % using bus priority control.

3. METHODOLOGY

The evaluation of the effectiveness of the bus lane system in Kuala Lumpur City involved the five steps shown in Figure 3.

Since traffic congestion in Kuala Lumpur City is critical only during morning and evening peak periods, the effective operation of the bus lane system during these peak times is much more critical compared to other times. Emphasis was therefore placed on evaluating the effectiveness of the system during peak periods because this represented the performance of the system in Kuala Lumpur. The issues addressed in this study were:

- How long does it take for buses travelling to the same destination to travel between various bus stops?
- How long does it take for the same bus if it travels on ordinary roads compared to travelling on the bus lane system?
- How suitable is the bus lane system for Kuala Lumpur City?



1.1 Figure 3: Major steps taken to determine the effectiveness of bus lane system

The next step was to identify those variables and constraints related to the development of the simulation model. The variables included:

- length of the bus-lane
- Inter-arrival time (i.e. time between bus stops) of buses travelling to the same final destination
- Inter-arrival time of passengers at the bus-stop taking the same bus
- Stopping time of the bus at the bus-stop when loading and unloading passengers
- Speed of travel of the bus

In order to simulate the bus lane operation system in Kuala Lumpur, site investigations were first conducted. It was found that the main two conditions which influenced travel time were:

- Buses stopping for the purpose of loading and unloading passengers
- Buses approaching to junction

There conditions are described in Figures 4a and 4b.

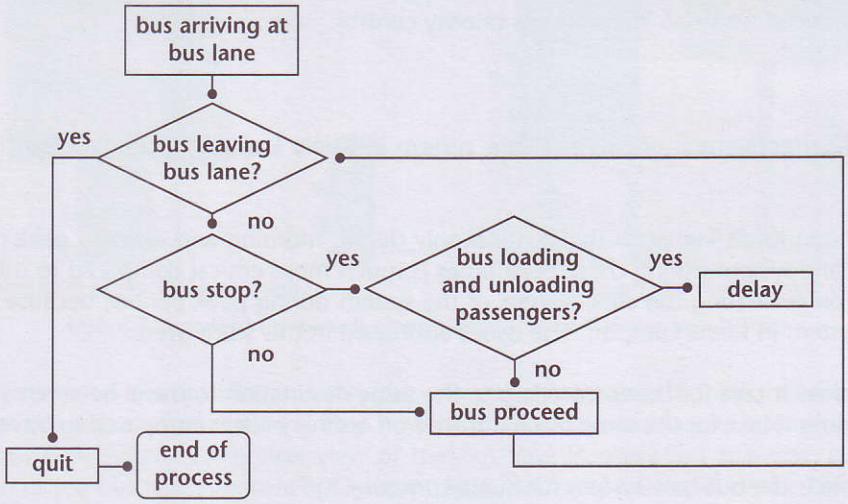


Figure 4 (a): Modelling buses approaching and departing bus stops

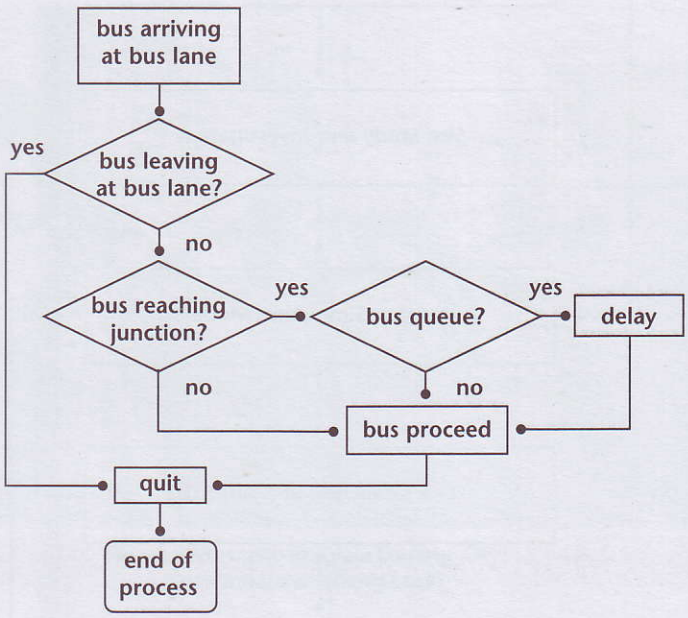


Figure 4 (b): Modelling buses approaching a junction

The simulation model was developed using these two conditions. The next stage of the study was to collect the following on-site data during peak periods for input into the models.

(a) **Bus Data**

- bus number
- bus inter-arrival time
- bus frequency of stop at bus-stop
- bus stopping time at bus-stop for the purpose of loading and unloading
- bus arriving time at bus lane
- bus departure time from bus lane

(b) **Passenger inter-arrivals**

(i.e. arrivals at bus stops which are not the final destination)

(c) **Traffic Light Data**

- cycle time
- green time and red time
- inter-arrival time of pedestrians using the push-button pedestrian traffic lights

(d) **Bus Lane Data**

- bus lane length

- bus lane width
- bus lane sign board

(e) **Environment Data**
- speed limit of the road
- location of junctions along the road
- location of traffic light along the road
- location of bus-stops along the road

The simulation model of buses travelling along the bus lane compared to ordinary roads was then carried out. Bus arrival rates and passenger arrival and departure rates were Poisson distributed and the inter-arrivals of buses, passengers and pedestrian were Negative Exponential distributed. These random variables were generated prior to the simulations being conducted. One-way ANOVA equal variance analysis was then used to calculate the effectiveness of the bus lane system.

4. RESULTS AND DISCUSSION

Site observations suggested that, during peak periods, the buses were travelling at average speeds between 30 km/h and 50 km/h in the bus lane but only at a maximum speed of about 25 km/h when they were not using the bus lane.

The following results were obtained from sets of simulations using data collected on 500 m length of the bus lane system along Jalan Raja Laut.

4.1 Total Travel Time

Table 1 shows the results of the simulations of the total travel time for all buses travelling along the bus lane over a 1 hour period during peak traffic.

The first hypothesis tested was:

H0: total travel time for all buses travelling at different speeds is the same:

$$H0: t20 = t25 = t30 = t35 = t40 = t45 = t50$$

and

H1: at least one set of the total travel time of buses travelling at different speeds is not the same:

$$H1: t20 \neq t25 \neq t30 \neq t35 \neq t40 \neq t45 \neq t50$$

Table 1: Total Travel Time for All Bus Over a 1 hour Period

Average Travel Speed (km/h)	Simulation 1	Simulation 2	Simulation 3	Simulation 4
	Total Travel Time (s)			
20	6091	5774	5917	5401
25	4884	4801	5064	4406
30	4242	4041	4567	3876
35	3731	3565	4092	3447
40	3422	3181	3478	3158
45	3232	2992	3277	2935
50	2975	2740	3088	3654
Total Buses	56	53	55	51

The results of the ANOVA (Tukey test) showed that, at the 95% significance level:

$$t30 = t35$$
$$t35 = t40$$
$$t40 = t45 = t50$$

In other words, in some cases, the total travel time varied with the speed of travel. The results suggest that if buses travel along the bus lane at an average speed of 40 km/h, then there were no significant differences in travel time compared to buses travelling at average speeds of 45 km/h or 50 km/h. On the basis of this analysis, if buses are travelling at an average travel speed of 40 km/h, then the bus lane is being fully utilised.

4.2 Average Travel Time

Table 2 shows the results of the simulations of the average travel time for each bus travelling along the bus lane at different speeds.

Table 2: Average Travel Time for Buses Travelling at Different Speeds

Average Travel Speed (km/h)	Simulation 1	Simulation 2	Simulation 3	Simulation 4
	Average Travel Time per Bus (s)			
20	108.77	108.94	107.58	105.90
25	87.21	90.58	92.07	86.39
30	75.75	76.25	83.04	76.00
35	66.63	67.26	74.40	67.59
40	61.11	60.02	63.24	61.92
45	57.71	56.45	59.58	57.55
50	53.03	51.70	56.15	52.04

The second hypothesis tested was:

H0: the average travel time of buses travelling at different speed is the same:

$$H0: t20 = t25 = t30 = t35 = t40 = t45 = t50$$

and

H1: at least one set of average travel time of buses travelling at different speeds is not the same:

$$H1: t20 \neq t25 \neq t30 \neq t35 \neq t40 \neq t45 \neq t50$$

The results of the ANOVA (Tukey test) showed that, at the 95% significance level:

$$t40 = t45$$
$$t45 = t50$$

In other words, in some cases, the average travel time varied with the speed of travel. The analysis showed that the travel time of buses travelling at an average speed of 40 km/h was no different to that of a bus travelling at an average speed of 45 km/h. Similarly, the travel time was no different for buses travelling at average speeds of 45 and 50 km/h.

Overall, the results show that the Kuala Lumpur City bus lane system is effective in increasing the travel speed of buses and hence travel time. As a result, more trips are generated during peak hour traffic.

4.3. Discussion

At Jalan Raja Laut, where the simulation was conducted, vehicles travelling along the road obey the rules and regulations of the bus lanes operation system.

Most of the vehicles other than buses travel outside the bus lane. However, some problems arise when vehicles have to do a left-hand turn. Some weaving of traffic occurs because there are a large number of junctions, and hence left-turning vehicles, along the bus lane. This sometimes forces buses to travel outside the bus lane.

At some locations, such as Jalan Pudu and Jalan Cheras the bus lane system was not so effective because a lack of strict law enforcement, particularly related to vehicles parking along the bus lane. This means that buses have to weave in and out of the bus lane and stop or slow down when they are moving along the bus lane. As a result, most of the buses try to avoid using the bus lane. An increased in the level of enforcement of the road laws to discourage drivers from parking in the bus lane will result in an increased level of efficiency in usage of the bus lane.

5. CONCLUSIONS AND RECOMMENDATIONS

The objective of the study described in this paper was to evaluate, using simulation, the effectiveness of the Kuala Lumpur City bus lane system during peak periods.

It was found that, in some cases, the total travel time varied with the speed of travel. The results suggest that if buses travel along the bus lane at an average speed of 40 km/h, then there were no significant differences in travel time compared to buses travelling at average speeds of 45 km/h or 50 km/h. On the basis of this analysis, if buses are travelling at an average travel speed of 40 km/h, then the bus lane is being fully utilised.

It was also found that, in some cases, the average travel time varied with the speed of travel. The analysis showed that the travel time of buses travelling at an average speed of 40 km/h was no different to that of a bus travelling at an average speed of 45 km/h. Similarly, the travel time was no different for buses travelling at average speeds of 45 and 50 km/h.

Overall, the operation of the bus lane system in Jalan Raja Laut (intersection of Jalan Parlimen to Jalan Dang Wangi) was found to be effective with the travel time for buses shortened when they travelled along the bus lane system. Even though there were no relative differences between the total travel time when buses travelled at 40, 45 and 50 km/h, the use of the bus lane system resulted in a decrease in total travel time. This resulted in an increase in the number of trips and a decrease in passenger waiting time.

An increase in the level of enforcement of the road laws to discourage drivers from parking in the bus lane at some locations will result in an increased level of efficiency in usage of the bus lane.

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THE KOREA HIGHWAY CORPORATION TEST ROAD

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ABSTRACT

The Korea Highway Corporation Test Road is a major full-scale road-testing facility recently commissioned by the Korea Highway Corporation. The main purpose of the test road is to investigate pavement technology issues of concern to Korea, with the ultimate aim being to develop a Pavement Design Guide suitable for Korean conditions. The data will also be used in various research projects addressing issues of concerns to pavement design engineers in Korea. The test road is 7.7 km long and consists of 25 concrete pavement sections and 33 asphalt pavement sections of various thickness and materials. A total of 1900 gauges of various types have been installed to measure pavement response. Climatic conditions are also being monitored. On-site facilities are also provided to manage data acquisition and analysis.

This paper describes the Korea Highway Corporation test road, including its construction, the test sections and the results of a pilot study conducted prior to the facility being opened to traffic in March, 2004.

2. INTRODUCTION

The Korea Highway Corporation Test Road is a major full-scale road-testing facility recently commissioned by the Korea Highway Corporation. The facility was opened in March 2004 following almost seven years of planning and a pilot study. The main purpose of the test road is to investigate pavement technology issues of concern to Korea, with the ultimate aim being to develop a Pavement Design Guide suitable for Korean conditions.

The test road is 7.7 km long and consists of 25 concrete pavement sections and 33 asphalt pavement sections of various thickness and materials. A total of 1900 gauges of various types have been installed to measure pavement response. Climatic conditions are also being monitored. On-site facilities are also provided to manage data acquisition and analysis.

This paper describes the construction of the test road, the types of pavements and gauges installed and the results of the pilot study conducted before the facility was officially opened.

3. CONSTRUCTION OF THE TEST ROAD

The test road is located adjacent to the existing four-lane Jungbu Inland Expressway, about 1 km south of Yeoju Junction. The construction of the test road required the provision of two additional lanes, each 7.7 km long (Figure 1). This site was selected because of its good geometric properties and high level of surface smoothness. It is also located at a site where high levels of heavy vehicle traffic are expected in the future. Figure 2 shows an overall plan of the test road.

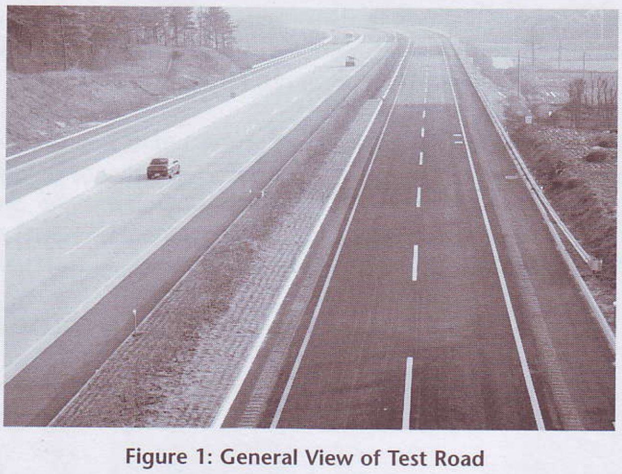

Figure 1: General View of Test Road

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Twenty-five concrete pavements are installed in a 2.83 km length of the test roads, whilst 33 asphalt pavements are installed over a 2.71 km length of the test road. Three bridges and two culverts are also present within the test road length. As a result, it will be possible to undertake investigations of all relevant issues including pavements, structures, geotechnical engineering, traffic, materials, environment, etc.

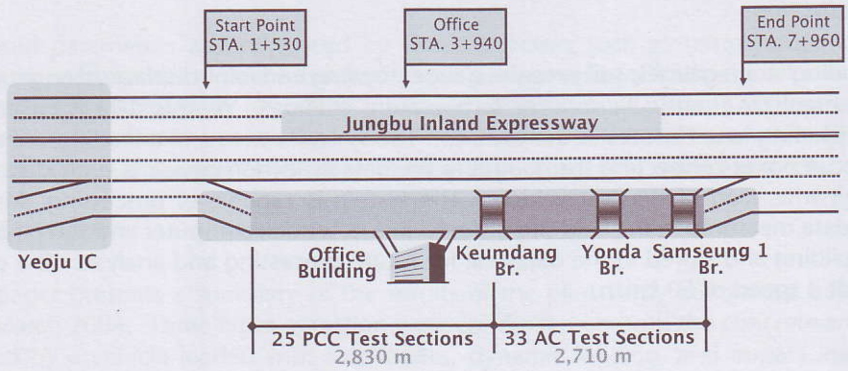


Figure 2: Overall Plan of Test Road

The cross-sections of the concrete pavement can be grouped into two major types: jointed plain concrete pavement (JPCP) and continuously reinforced concrete pavement (CRCP). Twenty two of the concrete pavements are JPCP and three are CRCP.

For the JPCP, there are three slab thicknesses (250, 300, 350 mm), three subbase thicknesses (120, 150 and 180 mm), and three subbase materials (lean-mix concrete, aggregate, asphalt stabiliser). Although this represents 27 combinations of pavement the aggregate subbase and the subbase layer treated with asphalt stabiliser were only applied to the 150 mm thick subbase whilst the lean-mix concrete subbase layer was applied in all cases. The main variable in the CRCP is the ratio of steel reinforcement (0.6, 0.7, 0.8%). In addition, however, a steel-fibre reinforced concrete pavement, a pavement with a high-strength lean-mix concrete subbase, a pavement without a frost-resistant layer, and a pavement with a drainage base layer without dowel bars were also constructed.

The design variables for the 15 dense-graded asphalt pavements are base thickness (150, 250 and 350 mm), three base materials (asphalt with 25 mm aggregate, asphalt with 40 mm aggregate, bitumen-stabilised aggregate) and three subbase thicknesses (300 mm, 300 mm with frost-resistant layer, 400 mm). Although this represents 27 possible combinations, the stabilised aggregate was only applied to the basic cross-section (300 mm thick subbase plus frost-resistant layer). The stabilised 25 mm aggregate, which is the basic design method adopted by the Korea Highway Corporation, was applied in all cases. In order to examine the performance of different surfacing types, the basic cross-section was surfaced with both PMA and SMA surfacings. As a result, a total of 33 cross-sections were constructed.

The layout of the test pavements took account of practical construction considerations. The thickness of the frost resistant layer was adjusted to ensure that surface evenness was maintained. The material types were also grouped together. Figure 3 shows the typical cross-sections of the various pavement types, together with the location of the gauges installed in the pavements.

4. DATA COLLECTION SYSTEMS

Three types of data collection systems have been provided: automatic, manual and continual. These are now briefly described. Table 1 shows general details of the gauges that have been installed in the pavements.

Table 1: Gauges Installed in KHC Test Road

Pavement Type		Concrete	Asphalt
PCC strain gauge		638	–
steel strain gauge		48	–
asphalt strain gauge		36	374
mold strain gauge		132	–
soil pressure gauge		34	66
Multi-Depth Deflectometer		4	6
curling displacement gauge		51	–
joint displacement gauge		120	–
thermister or thermocouple		140	112
frost depth gauge	thermister	30	39
	moisture content gauge	30	39

3.1 Automatic Data Collection

Thermostat and moisture gauges are used to automatically measure temperature and moisture content changes in the pavement layers due to environmental changes (Kwon et al. 2003). The system consists of a static data logger and fibre-optic modem, which is installed at 15 locations along the test road. The data logger is equipped with a rechargeable battery to avoid loss of data during power failures.

3.2 Manual Data Collection

Instrumentation including strain gauges, soil pressure gauges, curling and joint displacement gauges, etc. measure the response of the pavement to a particular load or temperature changes. As this data is collected manually, traffic control is required, including lane closures at the test site. The system consists of a loading control system to apply a particular load, 58 circuit boxes connecting the gauges to the data collection device, a static data logger, and a system for measuring the dynamic load of the test vehicle. The system is capable of processing signals from 48 gauges simultaneously. The data measured in the field site is stored in a notebook computer and then transported to the main server in the office building and stored in the database for future processing and analysis. The dual-wheel 4.2 tonne loading was applied at a speed of 50 km/h.

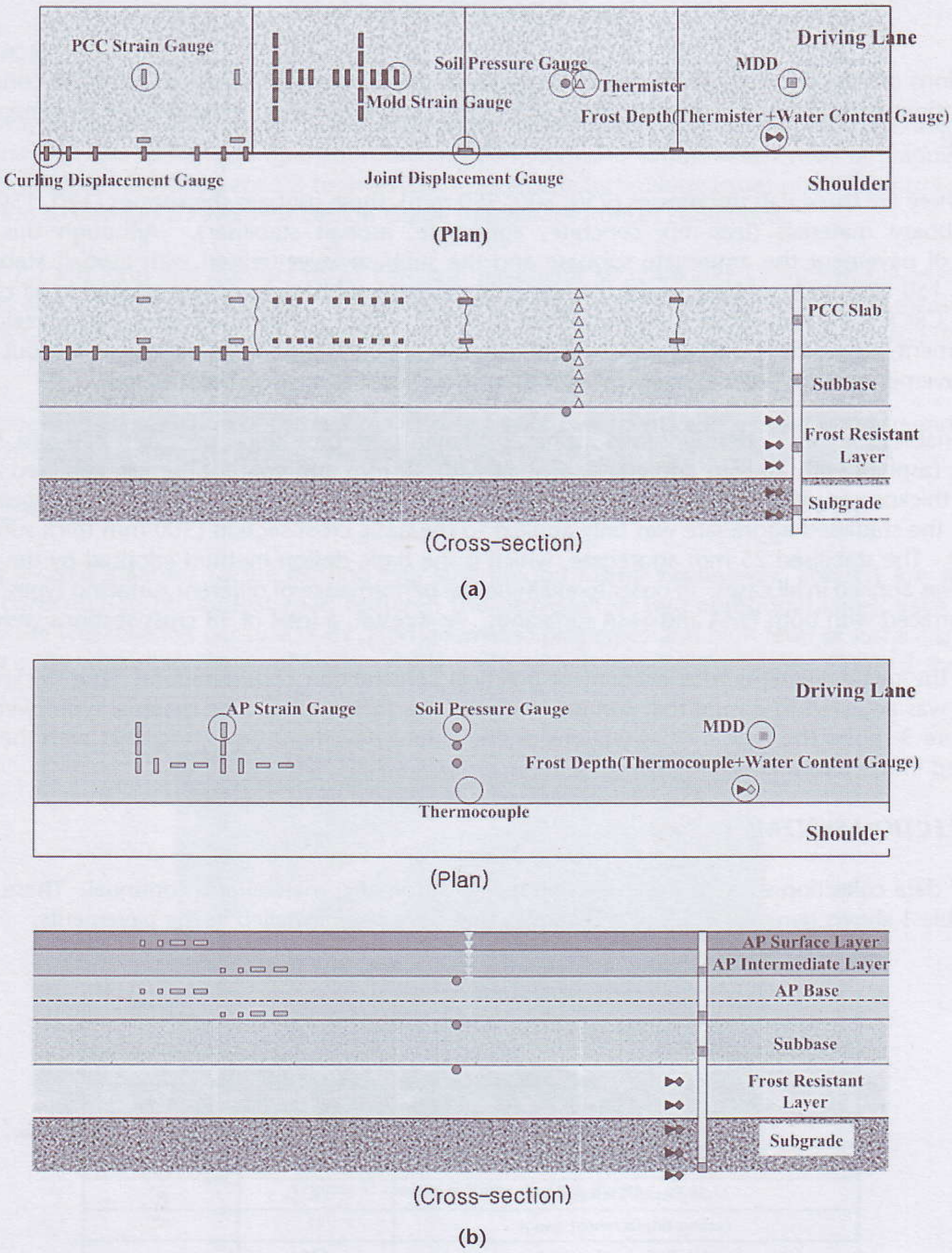


Figure 3: Location of Sensors in Test Road
(a) Concrete Pavements; (b) Asphalt Pavements

3.3 Continual Data Collection

A weigh-in-motion (WIM) system was installed to accurately measure the characteristics of the traffic using the test road. The data collected includes vehicular type, axle weight, total weight, speed of travel, axle spacing, distance between vehicles, etc. The current system can collect data for vehicles travelling at speeds up to 200 km/h and axle weights to an accuracy of ±7%. This system is composed of two columns of WIM separated by 4.1 m per lane, a front loop and a central loop.

Many of the measured parameters are influenced by climatic factors such as temperature and wind speed. For example, prevailing temperature has a great influence on the performance of both asphalt and concrete pavements. Because of this, it is necessary to revise or adjust the measured values to take account of these variations. In response to these needs, an automatic weather observation station was installed at the site to measure climatic factors that can influence pavement behaviour, including wind speed, temperature, humidity, rainfall and solar radiation.

5. RESULTS OF PILOT STUDY

This section of the paper presents a summary of the results of the pilot study conducted before the test road was officially opened in March 2004. Three types of testing were conducted on both the concrete and asphalt pavements: static loading applied by a vehicle loaded with steal plates, dynamic loading, and impact loading applied using a Falling Weight Deflectometer (FWD).

Table 2 summarises which gauges were monitored in the three phases of testing and also the measurement method, whilst the dimensions of the truck and the wheel load used in the static loading test are shown in Figure 4.

Table 2: Gauges Monitored During Testing and Measurement Method

Measurement Type	Gauge		Measurement Type
automatic	temperature, moisture content		30 minute intervals
manual	WIM, climate		24 hour real time
continual	concrete pavements	strain soil pressure	static loading dynamic loading FWD impact loading
		joint displacement curling	real time as temperature changes
		displacement	loading
	asphalt pavements	strain soil pressure	dynamic loading FWD impact loading

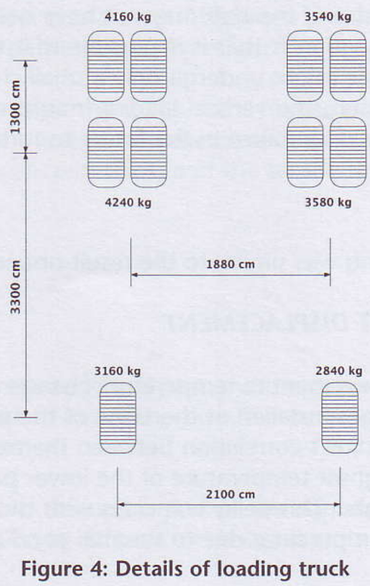


Figure 4: Details of loading truck

4.1 Concrete Pavement Section

Result of Static Loading Testing

The static loading test was performed by applying the load on top of the gauge for 10 seconds and then removing the load. There was a significant increase in compression and tension with depth in both the upper part of the aggregate base layer and the upper part of the frost resistant layer.

Results of Dynamic Loading

Figure 5 shows the maximum strains measured on the centre of the slab. It can be seen that, as the thickness of the slab increases, the relative changes in strain decrease. Repeatability testing conducted on slabs of the same thickness with the same load yielded satisfactory results, with the standard deviation of the response being 0.90-1.64 microstrain.

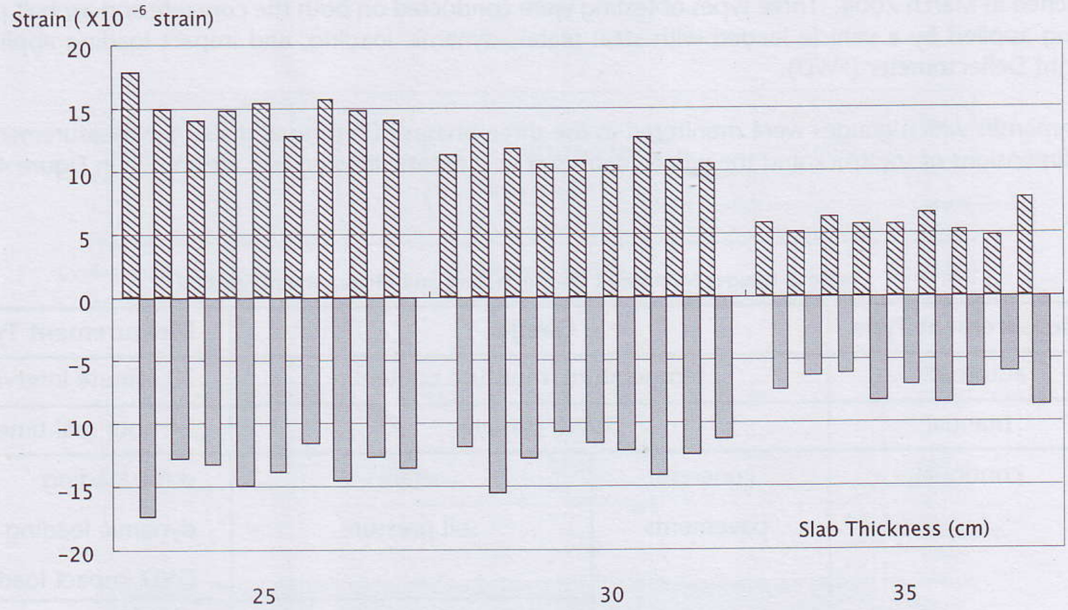


Figure 5: Maximum compressive and tensile strains per slab thickness (50km/h,4.2 t wheel load)

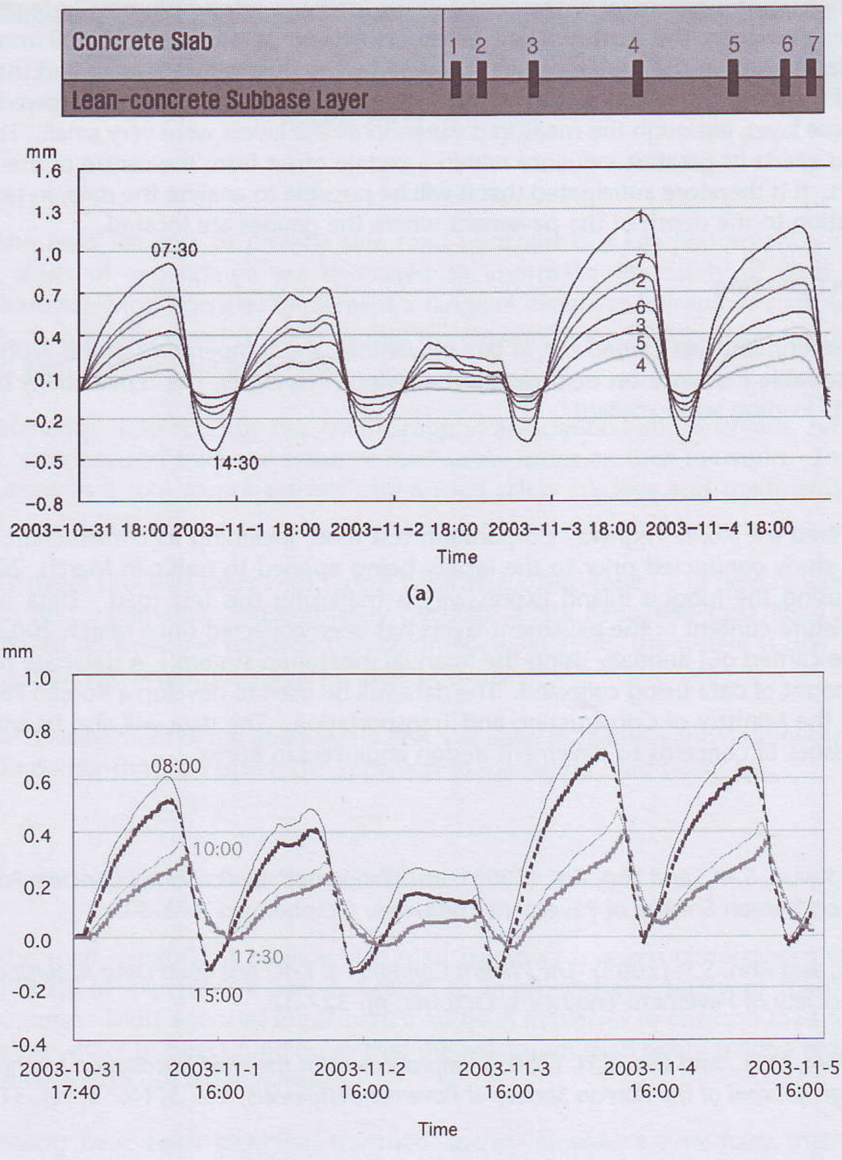
When the 4.2 tonne dual-wheel loading was applied at a speed of 50 km/h, the strains in the concrete slab and lean-mix concrete subbase were predictable in terms of their variation with depth. On the other hand, the strains measured by the soil pressure gauges in the lean-mix concrete subbase, which was located above the frost-resistant layer, were smaller than those in the frost-resistant layer. There are two possible explanations for this observation. The first is that the temperature in the upper part of the slab was quite high, probably due to the fact that the testing was conducted in the mid-afternoon. As a result, the centre of the slab may not have been in full contact with the top of the lean-mix concrete subbase. The second explanation is that it is possible that the soil pressure gauges embedded in the upper part of the lean-mix concrete subbase might undergo only a small change in compression because the material has a relatively high stiffness and, as a result, the vertical loading might not have exerted as much an influence as expected. A more detailed analysis will be undertaken in the future to further explain these observations.

RESULT OF FWD IMPACT LOADING

The response of the gauges to FWD loading was similar to the result obtained in the dynamic loading test.

MEASUREMENT OF CURLING AND JOINT DISPLACEMENT

The change in behaviour of the concrete pavement to temperature change was measured over seven consecutive days using curling and joint displacement gauges installed at the edge of the pavement adjoining the road shoulder. As shown in Figures 6a and 6b, there was a direct correlation between the response of the upper and lower part of the joint and change in temperature. The highest temperature of the lower part of the slab was attained 2 to 2.5 hours later than that of the upper part of the slab. This delay coincides with the time delay between the upper and lower part of the slab reaching the maximum temperature due to thermal conduction.



(b)

Figure 6: Curling and Joint Displacement of Concrete Pavement
(a) Curling displacement; (b) Joint displacement

Seven curling displacement gauges were placed in each slab on the edge at the road shoulder between the upper part of the lean-mix concrete subbase and the lower part of the slab and positioned so that they could measure the vertical displacement of the slab with respect to the subbase. The thickness of the subbase was 120-180 mm, which was about half the thickness of the slab. As the subbase is below the slab, it is rather insensitive to changes in temperature. As a result, the vertical displacement of the subbase due to the temperature changes was much smaller that the curling displacement of the slab. The relative vertical displacement between the slab and the subbase was therefore assumed to be the amount of curling displacement of the slab at the edge.

It was found that the vertical displacements at the joints were higher than those in the centre of the slab, which reflected the observed curling behaviour of the slab. On the basis of this testing, it is hoped that it will be possible to satisfactorily analyse the behaviour of the concrete slabs, and the tensile stress distribution with them, once sufficient climatic and response data are collected.

4.2 Asphalt Pavement Section

Results of Dynamic Loading Testing

Strains were measured in the surface and intermediate layers, and the upper and lower part of base at a speed of travel of 40 km/h. As testing was conducted in late November, the temperature of the asphalt was too low to exert any noticeable influence on deformation behaviour.

Soil pressure gauges were also embedded in the upper part of the aggregate base layer, the subbase layer, and the frost-resistant layer. The gauges were located at different depths and at the centre of the load and at offsets 500 mm and 1 metre from the load.

The magnitudes of the compressive strains at the centre of the load were highest in the aggregate base layer, followed by the subbase layer and then the frost-resistant layer. However, at an offset of 500 mm from the load, the compressive strain was highest in the subbase layer, followed by the frost-resistant layer and then the aggregate base layer. At an offset of 1 metre, the strains in the frost-resistant layer were the highest, followed by the subbase layer and the aggregate base layer, although the measured values in all the layers were very small. The explanation for this is that the wheel load exerts its greatest influence within a certain offset from the centre of the load in relation to the thickness of the layers. It is therefore anticipated that it will be possible to analyse the data, in terms of the distribution of the loading in relation to the depth of the pavement where the gauges are located.

Result of FWD Impact Loading

Once again, as the experiment was carried out in late November, the temperature of the asphalt pavement was too low to exert any noticeable influence on deformation behaviour. However, the repeatability of the response of the pavement to the FWD loading was excellent.

6. CONCLUSIONS

This paper has described the Korea Highway Corporation test road, including its construction, the test sections and the results of a pilot study conducted prior to the facility being opened to traffic in March, 2004. Currently all the south-bound traffic using the Jungbu Inland Expressway is trafficking this test road. Data such as the change in temperature and moisture content of the pavement layers has been collected since March 2003. Scheduled seasonal measurements will be carried out annually using the 'manual measuring system'. A database has been developed to manage the large amount of data being collected. The data will be used to develop a Korean Pavement Design Guide under the auspice of the Ministry of Construction and Transportation. The data will also be used in various research projects addressing issues of concerns to pavement design engineers in Korea.

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USE OF ROAD SAFETY RISK MANAGER IN PRIORITISING ROAD SAFETY WORKS

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ABSTRACT

The management of the road network to provide safe road transport is a key performance indicator for all road agencies. Significant levels of expenditure are dedicated to improving the safety of road infrastructure using engineering countermeasures. Most agencies implement a range of initiatives to improve road safety. The challenge faced by asset managers is where to direct funding so that the maximum road safety trauma reductions are achieved and the risks associated with road use are minimised.

The Road Safety Risk Manager, developed by the ARRB Group in association with Austroads, provides road agencies with a tool to manage, prioritise and track the status of road safety issues on their networks. The focus is to provide road safety professionals with a tool to pro-actively assess road safety hazards and treatments for the purpose of prioritising actions.

The Road Safety Risk Manager provides users with simple wizards, look-up tables and help functions to assess the risk associated with hazards and treatments, and ultimately calculate a Risk Reduction Cost Ratio that can be used to prioritise treatments. Based on extensive research that commenced in 1998, the system is user friendly and suitable for use by auditors, investigators, project managers and asset owners.

This paper describes the development of the Road Safety Risk Manager, its features and its application as a tool to assist road safety managers to demonstrate a responsible approach to managing road safety risk.

1. INTRODUCTION

1.1 Background

The management of the road network to provide safe road transport is a key performance indicator for all road agencies. Significant levels of expenditure are dedicated to improving the safety of road infrastructure using engineering countermeasures. Most agencies implement a range of initiatives to improve road safety. The challenge faced by asset managers is where to direct funding so that the maximum road safety trauma reductions are achieved and the risks associated with road use are minimised.

When road safety concerns have been identified the road agency requires a systematic method to prioritise the required treatments. A difficulty is that available budget provisions will often not allow all the outstanding issues to be addressed. The challenge for a road agency, therefore, is to plan, manage and take action to maximise the road safety return from the available budget.

1.2 Benefits of Pro-Actively Treating Hazardous Locations

Traditionally 'engineering' road safety programs have focused on the reactive implementation of engineering safety solutions at locations that have a demonstrated crash problem (i.e. Hazardous Road and Mass Action programs).

To determine the safety benefits that may be derived from pro-active road safety auditing programs, the ARRB Group carried out a major study for Austroads to identify and measure this benefit. The analysis of a range of existing road safety audits indicated benefit-cost ratios (BCRs) of implementing the proposed actions ranged between 2.4:1 and 84:1. It was also found that the BCRs of individual proposed actions within the existing road audits ranged between 0.003:1 and 460:1 (Macaulay et al, 2002). In addition:

- over 78% of all proposed actions had BCRs > 1.0;
- approximately 47% of all proposed actions had BCRs > 5.0; and
- approximately 95% of proposed actions with a cost less than A$1,000 had BCRs > 1.0.

A key element in maximising the outcomes identified through the road safety audit process is to determine the order in which the deficiencies may be addressed so that the safety outcomes attainable within a constrained budget can be maximised.

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2. DEVELOPMENT OF ROAD SAFETY RISK MANAGER

ARRB group, in association with Austroads, have developed the Road Safety Risk Manager, which is a tool that can be used by practitioners to prioritise the order in which road deficiencies may be treated, thus ensuring that money spent pro-actively on road safety measure will achieve optimal outcomes.

The development of the Risk Manager commenced in 1998 and involved the following activities.

- A review of current methods for prioritising works resulting from road safety audits within Australia and New Zealand.
- A review of road safety audit literature from around the world, including a consideration of the risk management approaches utilised in non-road industries such as health, defence and nuclear power generation.
- An analysis of completed audits from around Australasia to determine the range of deficiencies identified in the road safety audit process.
- Investigation and analysis of the various methods and approaches to estimating risk, based on the range of deficiencies identified.
- Development and testing of a theoretical framework for prioritising works.
- Completion of two workshops with Australasian road safety experts to refine and confirm the theoretical process developed.
- An extensive literature review of road safety related crash countermeasures and their effect on crash reductions. This information was used to develop the risk profile for each deficiency type.
- Investigation of State and National crash rates and valuations of crash costs. This enabled an appreciatio to be gained of base line crash risk and typical crash severity.
- Finalisation of the theoretical process, and calibration of the models developed.
- An 18 month trial of a prototype by Australian and New Zealand road agencies.

3. DESCRIPTION OF ROAD SAFETY RISK MANAGER

The purpose of the Road Safety Risk Manager is to provide road safety professionals with a tool to pro-actively assess road safety hazards and treatments for the purpose of prioritising actions (see Figure 1). The tool adopts a risk management approach, with the ultimate aim of maximising the risk reduction on the road network for a given budget. The software also provides a means of tracking the status of outstanding issues and provides managers with user-friendly reporting options.

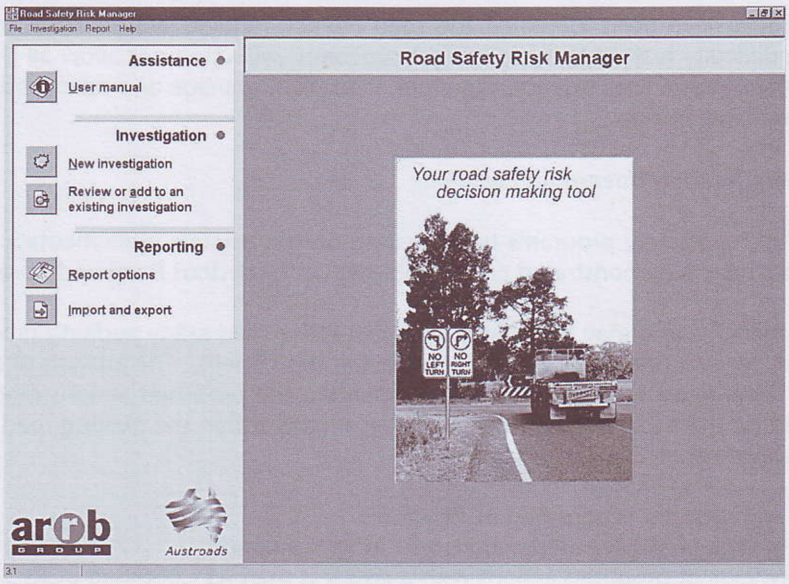

Figure 1: Road Safety Risk Manager software

The appropriate application of risk assessment knowledge will result in:

- reductions in the risk of road crashes / road trauma;
- reductions in the risk of fatal and serious injury crashes;
- economic benefits to the community as a result of fewer road crashes;
- reductions in the risk of successful legal action against road agencies that may result from road crashes; and
- the development of a 'safe road system' which will not tolerate fatal or serious crash injury outcomes, irrespective of the circumstances that lead to the occurrence of the incident.

The process is based on the measurement of risk as a function of exposure, likelihood and severity, and provides users with the ability to analyse the hazard risk and the treatment risk reduction for 57 different types of deficiencies, across a variety of different road types and severity outcomes. Following inclusion of treatment costs, the derived risk reduction cost ratio forms the basis of prioritising the proposed works.

The Risk Manager can be applied to a wide range of safety issues. As an example, the findings of a road safety audit can be assessed, potential treatments prioritised and a program of works developed within the budget constraints of the road agency.

Other areas where the Road Safety Risk Manager may provide assistance are:

- the prioritisation of a mass action program of works (e.g. guardrail, line marking, right turn lanes, etc.);
- assessment and prioritisation of safety-related routine maintenance and routine inspection operations;
- assessment and prioritisation of safety projects as part of a wider 'black-spot' program; and
- tracking the status of any safety issues and recording any action taken (closing the loop).

3.1 Key Components of the Process

The key components of the software include recording and analysis of the following:

Investigation Details

- information on the site, assessor and other project details (see Figure 2)

Exposure

- the number of vehicles that are exposed to the hazard and associated treatment

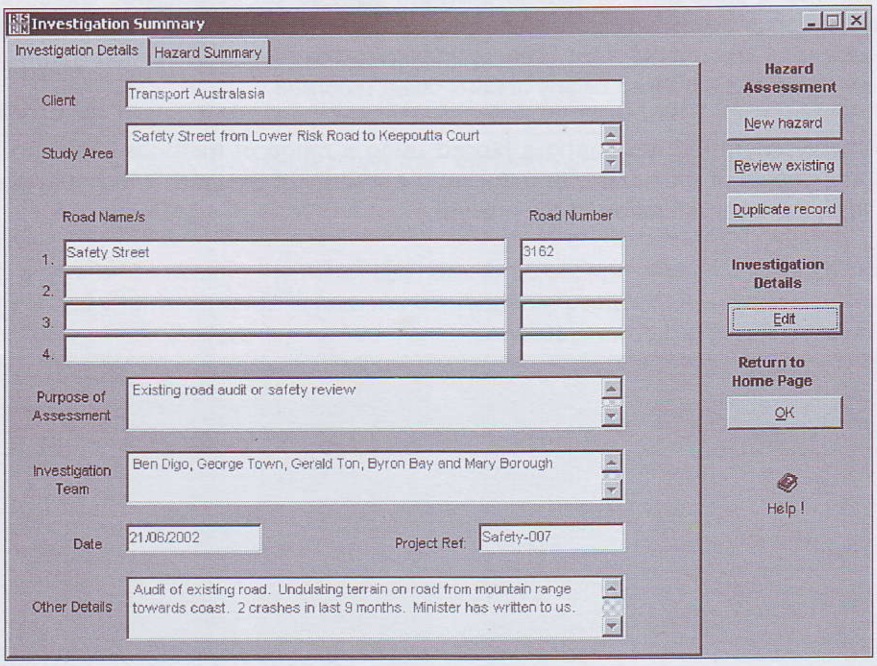

Figure 2: Investigation Summary screen

Likelihood

- the length of the hazard and associated treatment
- an assessment of the general crash risk at the location
- an assessment of the risk posed by the hazard and associated treatment
- an assessment of the degree to which other factors (e.g. weather, skid resistance) influence the risk at the site

Severity

- the severity of a crash if it does occur

Treatment Cost and Risk Reduction Cost Ratio

- the initial, ongoing and any salvage costs associated with the treatment
- calculation of the risk reduction cost ratio of the treatment

Action Taken

- details on the status of the issue (e.g. pending / completed)
- actual works planned or undertaken

Reporting and Budget Analysis

- a budget analysis tool to assess changes in treatment order
- different reporting and ranking options suitable for technical review through to management summaries

Exporting and Importing

- the ability to transfer records between users for overall program management

The individual hazard and treatment summary (see Figure 3) provides information on all the key data entered in the hazard and treatment assessment. The appropriateness of the data entered can be reviewed from this form, and any updates to action taken recorded. All assumptions made as part of the assessment can also be documented.

3.2 Application of Road Safety Risk Manager

These components are built into the Road Safety Risk Manager with simple wizards, look-up tables and help functions to provide a user-friendly system that can be used by auditors, investigators, project managers and asset owners. Following the collection of site information, the tool allows individual hazards and treatments to be assessed in 5-10 minutes. With the reporting and budget analysis tools provided, the software can meet the specific needs of risk identification, risk management and the development of remedial treatment programs.

Exporting and importing functions also allow the development of local area programs at the regional level, which can be easily incorporated into a state-wide or federal program such as the 'black-spot' initiatives. This allows the comparison and prioritisation of actions in a consistent manner across the program, and provides a targeted approach to funding those engineering treatments most likely to maximise the reduction in road trauma. The software also allows the status of any issue to be tracked or any actions taken recorded.

A road agency is primarily interested in treating a hazard using a range of methods including reducing exposure, removing or limiting the impact of the hazard, or reducing the severity of the crash if it should occur. The cost of the treatment is also an important consideration in the analysis.

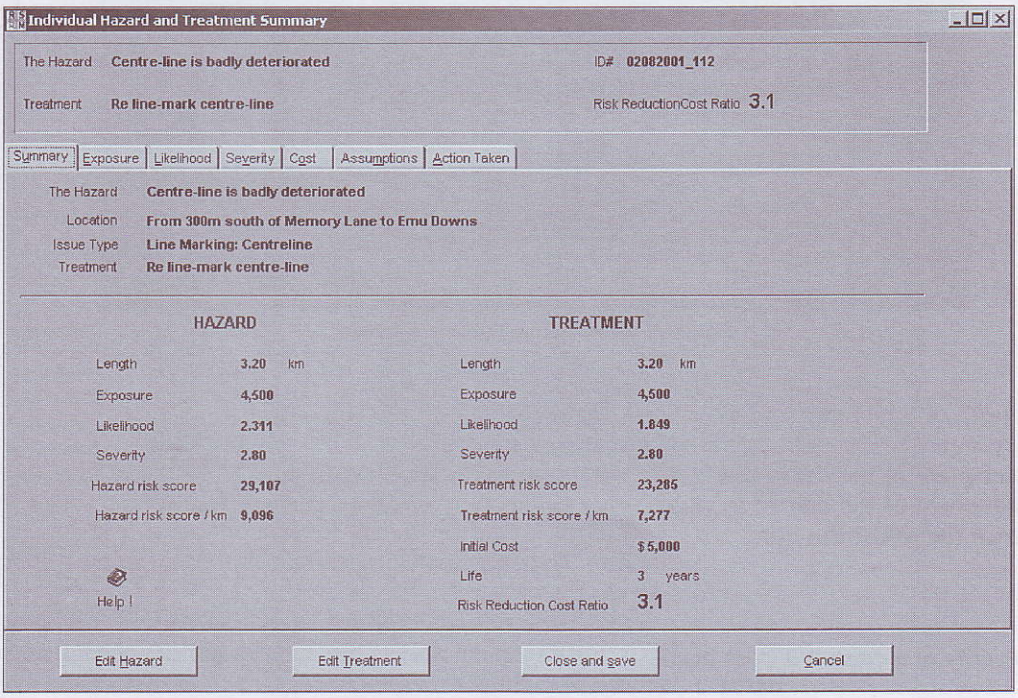

Figure 3: Individual Hazard and Treatment Summary form

Multiple Hazard and Treatment Report

Executive Summary

Report generated on 19 Jul 2002 17:03 **by** Rob McInerney

Road Name	The Hazard	Hazard Location	Proposed Treatment	Initial Cost	Risk Cost Ratio	Status
Safety Street	Badly deteriorated line-marking (centreline)	Gum tree flat from Koala Corner to Wombat Drive	Upgrade centreline (with reflective beads)	$ 3500	8.509	Action Pending
Safety Street	Badly deteriorated line-marking (edge lines)	Gum tree flat from Koala Corner to Wombat Drive	Repaint edgelines with reflective beads	$ 7000	2.250	Action Pending
Safety Street	Steep embankment on edge of road	Windy Road Pass - 63.8km mark on "Snake Corner"	Install guard-rail 0.5m from travelled lane	$ 11000	1.532	Action Complete
Safety Street	Poor skid resistance	Next to boggy swamp corner Ch 23.4	Resurface with high skid resistant 14mm	$ 6000	0.289	Action Pending
Safety Street	Sharp horizontal S bend curves	The hazard is at RRD 32.47, 2 km north of Animal Farm Rd	Realign curves and have straight section of road	$ 175000	0.203	Action Pending

Road Safety Risk Manager version 2.02.01 Copyright 2002. ARRB Transport Research Ltd. *Rob McInerney*

Figure 4: A sample report from the Road Safety Risk Manager

The system provides a means of assessing the risk of the hazards before and after treatment by providing a 'risk score' both prior to treatment and after treatment. In essence, the desirable treatment is the one which provides the greatest reduction in risk per dollar spent. Projects are ranked from those that provide the greatest reduction in risk per dollar spent, to those where the risk reduction per dollar spent is minimal (refer Figure 4 for a sample report from the Road Safety Risk Manager).

4. SUMMARY

Formal analysis of potential road safety treatments or audit recommendations, in conjunction with sound management practices and well planned remedial programs, will make a positive contribution to improving safety and may also assist road agencies to meet their duty of care in a responsible and transparent manner.

The Road Safety Risk Manager represents a new and innovative approach to managing safety issues on the road network by prioritising a wide range of road safety treatments. With appropriate training and use the Road Safety Risk Manager will provide road safety professionals and asset owners with an operational and management tool and lead to increased confidence in road safety decision making. This will help focus the work of road asset managers to improve safety and ensure that the maximum reduction in road trauma is achieved from the investment in road infrastructure.

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CONCEPTS OF RELIABILITY IN MECHANISTIC-EMPIRICAL BITUMINOUS PAVEMENT DESIGN

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ABSTRACT

The design of a bituminous pavement requires certain input parameters such as pavement temperature, subgrade strength, predicted traffic, layer stiffness, etc. Since all these parameters also have inherent variability, the mean values, or the most probable values, are generally assumed in the pavement design process. This essentially deterministic approach towards pavement design is adopted in various design methodologies, including the Mechanistic-Empirical pavement design approach, which is currently the most popular approach adopted throughout the world. This paper discusses the issue of the variability involved in the pavement design process and the estimation of the reliability of the design of a pavement derived using the Mechanistic-Empirical approach. This allows a designer to design a pavement to a given level of reliability, and hence allow a comparison of alternative pavement designs.

1. INTRODUCTION

The principle of the structural pavement design of bituminous pavements can be divided into two major groups: the Empirical approach and the Mechanistic-Empirical (M-E) approach. The empirical approach is based on empirical relationships developed from the field data and experience. On the other hand the M-E approach relies on stress-strain analysis of multi-layered pavement structures and field-calibrated empirical equations to obtain the design thickness values.

In the M-E pavement design approach, transfer functions used to relate the allowable traffic to the failure strains are calibrated using field performance data obtained on selected in-service roads over a certain period of time. However, the performance of the road to be designed will vary from the performance of the roads considered for calibration. There exists a considerable variation in input parameters due to the inherent variability of the pavement materials. For example, the elastic modulus at each location within the subgrade or base layer will vary, irrespective of the procedure adopted to compact the subgrade or base layers. This will in turn lead to variations in the allowable traffic.

Similarly, the expected traffic depends on input parameters such as the current traffic, the traffic growth rate, the design period, vehicle damage factors (VDF), lateral distribution factors (LDF), etc. Variations in these parameters will also result in variations in the predicted traffic.

A pavement design is considered to be satisfactory when the allowable traffic exceeds the predicted traffic (Harr 1987; Kenis and Wang 2004; Austroads 2004). Since there are variations in allowable traffic and predicted traffic, there exists a probability that the pavement may or may not fail. This leads to the concept of reliability in pavement design, which is discussed in the present paper.

2. PAVEMENT DESIGN USING THE MECHANISTIC-EMPIRICAL APPROACH

Structural pavement design is a process of determining the thickness of the various layers within a pavement for the prevailing conditions. In the M-E approach to bituminous pavement design, the pavement is typically idealised as a three-layered structure, viz. bituminous surface layer, unbound granular base layer and semi-infinite subgrade (see Figure 1) and some sort of loading system, the simplest being a Standard Axle with dual wheels (e.g. Chakroborty and Das 2003; Austroads 2004). The horizontal tensile strain (ϵ_t) at the bottom of the bituminous layer and the compressive strain (ϵ_z) at the top of the subgrade are considered to be the factors governing fatigue and rutting failure respectively. The concepts of fatigue and rutting failure and the need to balance the design are discussed further in the subsequent paragraphs.

2.1 Fatigue Failure

Repetitive loading on a pavement induces fatigue in the bituminous layer which is manifest as cracking at the bottom of the layer which eventually propagates through the surface. In line with current Indian guidelines, if 25% of the surface area is cracked then it is considered to have failed due to fatigue (Indian Roads Congress 2001). Different

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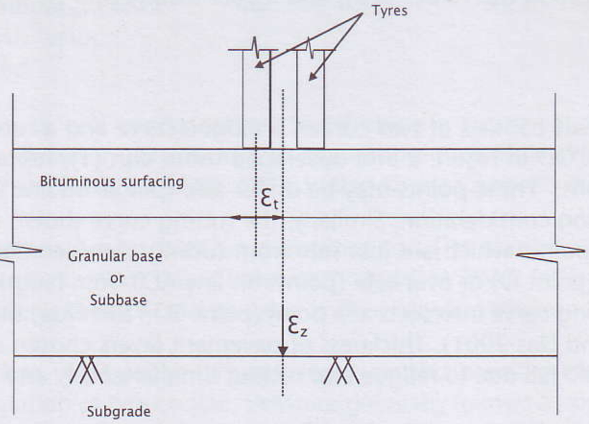

Figure 1: Typical bituminous pavement structure

countries follow different guidelines on this issue. The number of Standard Axle load repetitions sustained by the pavement before fatigue failure is known as the fatigue life. The following empirical fatigue equation is widely used for pavement design:

$$N_f = k_{1f} \times \left(\frac{1}{\varepsilon_t}\right)^{k_{2f}} \times \left(\frac{1}{E_1}\right)^{k_{3f}} \quad (1)$$

where N_f = fatigue life (Standard Axle repetitions)
k_{1f}, k_{2f}, k_{3f} = regression coefficients
E_1 = elastic modulus of surface layer
ϵ_t = tensile strain at the bottom of the bituminous layer

As per the Indian specification the values of k_{1f}, k_{2f} and k_{3f} are assumed to be 2.21×10^{-4}, 3.89 and 0.854 respectively.

2.2 Rutting Failure

Repeated vehicle loadings also induce permanent deformation in the wheelpath which results from densification and shear deformation of various layers. The Indian specification recommends that a maximum deformation of 20 mm represents failure of a pavement. The number of Standard Axle repetitions sustained by the pavement before the prescribed deformation is reached is considered to be the rutting life of the pavement. The rutting life is obtained using the following empirical equation:

$$N_r = k_{1r} \times \left(\frac{1}{\varepsilon_z}\right)^{k_{2r}} \quad (2)$$

where N_r = Rutting life in terms of standard axle repetitions
k_{1r}, k_{2r} = Regression coefficients of fatigue equation
ϵ_z = Compressive strain at the top of the subgrade

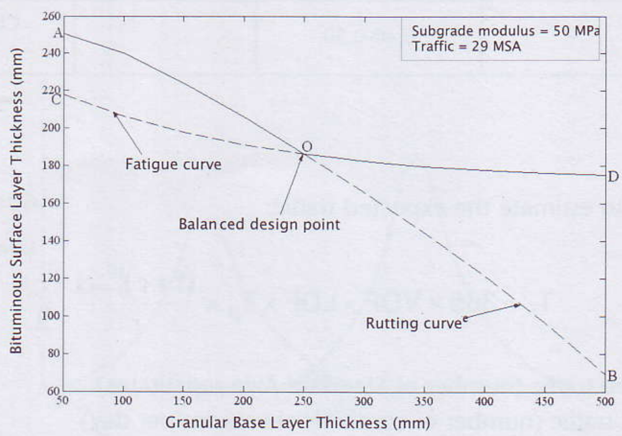

Figure 2: Typical pavement design chart

In line with the Indian specification the values of k_{1r} and k_{2r} are assumed to be 4.1656×10^{-8} and 4.5337 respectively.

2.3 Balanced Design Point

A typical pavement design chart consists of two curves, a fatigue curve and a rutting curve as illustrated in Figure 2. The fatigue curve, shown as COD in Figure 2 and developed using eqn (1), represents a set of points which are just safe from fatigue considerations. These points may be under-safe (points on line CO), just safe (point O) or over-safe (points on line OD) from rutting consideration. Similarly, the rutting curve shown as AOB in Figure 2 developed using Equation 2 represents those points which are just safe from rutting consideration. These points may be under-safe (points on line OB), just safe (point O) or over-safe (points on line AO) from fatigue consideration. In the design chart the fatigue curve and the rutting curve intersects at a point (point O in this case) that may be called as balanced design point (Narasimham, Misra. and Das 2001). Thickness of pavement layers chosen according to this point will result in a pavement deign which would fail due to fatigue and rutting simultaneously and can be assumed that the pavement materials are fully utilized.

3. VARIATION OF INPUT PARAMETERS

The input parameters for pavement design may be broadly categorised as pavement parameters and traffic parameters. This section presents a brief discussion regarding the variability of these parameters.

3.1 Pavement Parameters

A brief review on the variability of pavement parameters is presented in Table 1.

Table 1: Variations in Pavement Parameters

Parameter	Type of Distribution	Mean Value	Standard Deviation	Reference
Elastic modulus of surface layer	Normal	900-2000 MPa	250-400 MPa	Kenis & Wang (2004) Noureldin et al. (1994)
Elastic modulus of base layer	Normal	175-225 MPa	50-55 MPa	Kenis & Wang (2004) Noureldin et al. (1994)
Elastic modulus of subgrade	Normal	100-110 MPa	8.5-11 MPa	Kenis & Wang (2004) Timm et al. (1998)
Thickness of surface layer	Normal	according to design	6-7 mm	Darter et al. (1973) Kenis & Wang (2004) Kenis & Wang (1994) Timm et al. (1998) Timm et al. (1999)
Thickness of base layer	Normal	according to design	8-20 mm	Darter et al. (1973) Kenis & Wang (2004) Timm et al. (1999)
Poisson's ratio of surface layer	–	0.35-0.50	–	Chakroborty & Das (2003) Austroads (2004)
Poisson's ratio of base layer	–	0.20-0.50	–	Chakroborty & Das (2003) Austroads (2004)
Poisson's ratio of subgrade	–	0.40-0.50	–	Chakroborty & Das (2003) Austroads (2004)

3.2 Traffic Parameters

The following equation is used to estimate the expected traffic:

$$T_f = 365 \times VDF \times LDF \times T_p \times \frac{(1+r)^n - 1}{r} \qquad (3)$$

where T_f = expected traffic (number of Standard Axle repetitions)
T_p = present traffic (number of commercial vehicles per day)
VDF = Vehicle Damage Factor

LDF = Lateral Distribution Factor
r = traffic growth factor
n = design period

Since vehicles with different axle loads and configurations travel along a pavement, the pavement is exposed to different levels of damaging effects. A factor, VDF, is used to convert the individual axle loads into the total number of expected Standard Axle loads (Chakroborty and Das 2003; Indian Roads Congress 2001).

Vehicles do not follow exactly the same wheelpath rather a distribution. The number of repetitions of Standard Axle loading needs to be adjusted to take account of this (Chakroborty and Das 2003; Indian Roads Congress 2001) with a suitable factor. This factor is known as the LDF and its value is generally less than one.

Depending on the tyre type, the mean value of the tyre-pavement contact pressure may vary between 550 kPa and 700 kPa (Timm et al. 1999). The variation of tyre contact pressure generally follows a normal distribution. In addition, different codes of practice recommend different wheel spacing values (between the dual wheels) with mean values generally varying between 310 mm to 340 mm (Indian Roads Congress 2001; Austroads 2004; Shell 1978).

The parameter 'present traffic' is simply the number of commercial vehicles moving along the road each day. Another deterministic parameter, design period, is the number of years for which the pavement is expected to remain in serviceable condition.

4. CONCEPT OF RELIABILITY

Put simple, 'reliability' is a measure of the adequacy of the design. The traditional approach to estimating the adequacy of a design is through the use of the concept of 'factor of safety' (FOS) (Harr 1987). The FOS is calculated in terms of the number of allowable Standard Axle repetitions (M) and the expected number of allowable Standard Axle repetitions (m) as follows:

$$FOS = \frac{M}{m} \tag{4}$$

The pavement is considered to be 'safe' if the FOS is greater than 1. As discussed earlier, the allowable traffic and expected traffic are not deterministic quantities – there are always variations – and consideration of these variations gives rise to the concept of reliability.

The reliability of any system can be defined as the complementary of probability of failure of the system, i.e. 1 minus the probability of failure. For the particular case of pavement design it may be defined as the probability that the allowable traffic will exceed the expected traffic during a selected design period. Mathematically it can be represented as:

$$\text{Reliability} = P(M > m)$$
$$\text{i.e. Reliability} = P(M - m > 0) \tag{5}$$

The term (M – m) can be represented by another variable, S, or the 'safety margin' (Harr 1987). This parameter is a random variable which follows a distribution related to the randomness of M and m. In the simplest situation, if 'M' and 'm' are normally distributed then the distribution of 'S' would also be normal (Harr 1987).

The reliability is therefore governed by the amount of overlap of the probability distribution of M and m (shaded portion of Figure 3). The distribution of 'S' and the reliability of the pavement system is illustrated schematically in Figure 4.

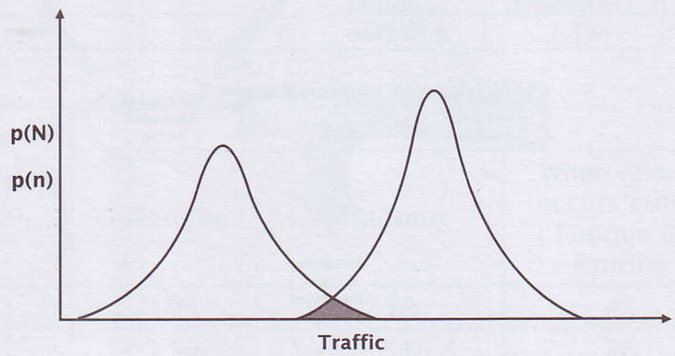

Figure 3: Typical probability distribution of allowable and applied traffic

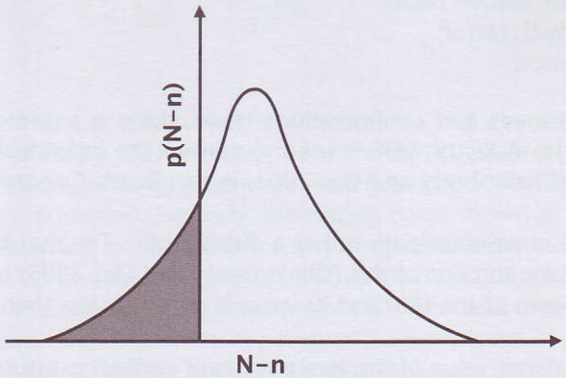

Figure 4: Typical probability distribution of safety margin (s)

The shaded area of Figure 3 is the probability of failure of the pavement system whilst the unshaded area is the reliability. Calculating the area of probability distribution curve of 'S', where 'S' is greater than zero, gives the reliability of the pavement system.

In other words, a pavement design reliability of 95% indicates that, out of 100 identically designed (and constructed) pavements, 95 of them would be expected to outlast the design period.

5. ESTIMATION OF RELIABILITY OF SELECTED PAVEMENTS

This section describes the process of evaluating the reliability of a selection of pavements. The process of reliability estimation, and some results of the reliability analysis for typical pavement sections, are presented in the following sub-sections.

5.1 The Process

The reliability estimation process is shown in Figure 5. The process is now discussed in more detail.

- In the first step, the variations in pavement design parameters (elastic modulus, Poisson's ratio, layer thickness, wheel spacing and tyre contact pressure) can be determined according to their nature of distribution. This may be done with the help of suitable random number generators. These variations in pavement design parameters are then used to calculate the variations in fatigue strain and rutting strain.

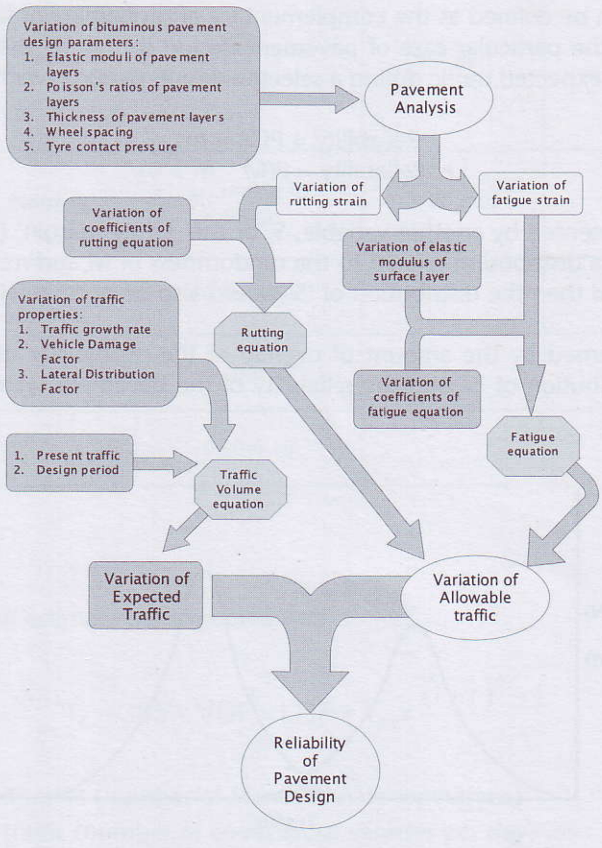

Figure 5: Flow Chart for Analysis Process

- Next, the variations in fatigue and rutting strain are transformed to allowable traffic using the fatigue and rutting equations (eqns (1) and (2)). This gives the variation of allowable traffic from both fatigue and rutting considerations.
- Similarly, the variation in expected traffic is determined using the traffic volume equation (eqn (3). Inputs to the traffic volume equation are present traffic, design period, traffic growth rate, VDF and LDF. The variations in traffic growth rate, VDF and LDF are determined using suitable random number generators.
- The variation in allowable traffic, in terms of both considerations (fatigue and rutting) and expected traffic, are then subtracted to obtain the variation of safety margin 'S' for fatigue and rutting respectively. The probability of this safety margin being greater than zero gives the reliability of the pavement design for both considerations.
- Finally, the overall reliability of the pavement section is determined depending on the failure criteria. The failure criteria that may be considered are fatigue failure only, rutting failure only, or both fatigue and rutting failure etc.

5.2 Results

Three different pavement sections were chosen for analysis based on the discussion in Section 2.3. The first section was just safe from the point of view of rutting but oversafe from the point of view of fatigue. The second section was the 'balanced design' section, i.e. just safe from both fatigue and rutting considerations. The third section was just safe from the point of view of fatigue but oversafe from the point of view of rutting. The details of the three sections (i.e. type of distribution, mean value and standard deviation) are given in Table 2.

Table 2: Properties Considered in the Analysis

Section No.	Type of Distribution	Asphalt Layer Thickness (mm)		Granular Layer Thickness (mm)	
		Mean	Std Dev.	Mean	Std Dev.
1	Normal	224	5	150	15
2	Normal	184	5	254	15
3	Normal	178	5	350	15

Simulation of 10,000 points was carried out for each of the pavement sections designed according to the Indian specification for fatigue and rutting failure. The pavement sections were designed for present traffic of 2,000 commercial vehicles per day and a design period of 10 years. The details of material and traffic properties considered in the analysis are given in Table 3 and the results, in terms of reliability, are shown in Table 4.

Table 3: Variation of Design Parameters Used in Analysis Process

Parameter	Type of Distribution	Mean	Standard Deviation
Elastic modulus of surface layer	normal	1500 MPa	150 MPa
Elastic modulus of base layer	normal	150 MPa	30 MPa
Elastic modulus of subgrade	normal	50 MPa	10 MPa
Poisson's ratio of surface layer	normal	0.45	0.03
Poisson's ratio of base layer	normal	0.35	0.05
Poisson's ratio of subgrade	normal	0.45	0.015
wheel spacing	normal	310 mm	0.4 mm
tyre contact pressure	normal	800 kPa	3 kPa
VDF	normal	4.0	0.6
LDF	normal	0.7	0.07
traffic growth rate	normal	7.5%	0.075%

Table 4: Pavement Reliability

Section No.	Reliability (%)		
	Fatigue	Rutting	When failure occurs either Fatigue or Rutting
1	93	52	48
2	50	51	26
3	50	91	46

From Table 4 it can be seen that the reliability values for Section 1 and Section 3 are high from the point of view of fatigue and rutting respectively. However, in terms of rutting and fatigue considerations, respectively, the reliability values are close to 50%. This is because the sections are deliberately selected to lie on the rutting and fatigue curves respectively (refer Figure 2). The fatigue and rutting reliability values for Section 2, the 'balanced design', are both close to 50%. This is because all the mean values were chosen as the input parameters. Essentially, a pavement designer needs to select suitable values for the input parameters, other than their mean values, in order to improve the reliability level.

6. CONCLUSIONS

This paper has discussed the issue of the variability involved in the pavement design process and the estimation of the reliability of the design of a pavement derived using the M-E approach. The parameters required for the design of pavement always have inherent variability. It is therefore preferable to consider the variations of the parameters in the design process, rather than considering them deterministic, as is generally the case with conventional M-E design. Also, determining the reliability will assist a designer to rationally compare alternative pavement design options.

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PAVEMENT ENGINEERING EDUCATION AT THE CROSSROADS – THE WAY AHEAD*

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ABSTRACT

This paper summarises the reasons behind the establishment of the International Centre for Pavement Engineering Education (ICPEE), outlines its development and operation and examines its likely future.

The changes occurring in the pavement industry worldwide since the late 1980s focused the attention of the Centre's founders on the need to provide education and training initiatives at a number of levels. ICPEE was formed to fill a specific void which existed in postgraduate pavement engineering education programs. The decade of the 1990s clearly has brought about a greater demand for the short courses and distance learning program offered by ICPEE which are aimed at the immediate needs of industry (private and Government sectors) and pavement engineers and technicians employed by industry. The Master of Technology in Pavements and Master of Engineering in Pavements are unique qualifications because they are heavily pavement industry-oriented. The provision of short courses based on ICPEE units is also an option for concentrated, short time-frame learning.

1. INNOVATION AND NEW TECHNOLOGY – THE DRIVERS FOR IMPROVED LEARNING

In a rapidly developing, technologically driven society, it is vital for any industry to keep up with the pace of change. This is especially true in road design, construction and maintenance and, in particular, the flexible pavements industry.

The need to achieve better results, often with fewer resources, is one of the factors which has placed greater emphasis on gaining significant improvements from pavement technology in recent years. The resultant technology, particularly with regards to flexible pavements, is 'revolutionising' the way roads and other paved surfaces are designed, constructed, maintained and rehabilitated. However, this 'new technology' will only be of benefit if it is understood and reaches the engineers who are designing pavements, or the construction specialists who are building and maintaining them.

Whilst pavements can be quite different from one country, or even region, to another due to available materials, climatic influences and local geology, the fundamentals in pavement technology are global. 'Common ground' presents opportunities to combine resources to achieve a significant benefit to all participants on an international scale never before attempted but never before needed so much.

Clearly, improved education and training, resulting in better pavement performance, will deliver significant economic benefits.

As a first step, in 1994, a Centre for Pavement Engineering Education (CPEE) was created as a national body in Australia. Its objective was to provide education and training and, as a secondary objective, to coordinate applied research for those engaged in pavement technology and the road pavement industry. CPEE which is a partnership between Government Road Agencies and private industry represented by the Australian Asphalt Pavement Association (AAPA), created postgraduate distance learning study 'units' designed to enhance engineering outcomes in pavement design, construction and maintenance. This has recently been broadened to include units in asset management and business administration.

Working primarily through Australia's Latrobe University, but also with other selected individual tertiary educational institutions, CPEE provides a logistically superior solution to the problems of time and distance facing many students. The Master of Technology in Pavements and Master of Engineering in Pavements are unique and innovative since they tie the qualifications specifically to an industry as distinct from an open mix of subjects.

2. DETAILS OF STUDY UNITS

The following 'pavement' units are offered in the course.

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CPE 650	Introduction to Pavements
CPE 651	Pavement Design
CPE 652	Flexible Pavement Construction
CPE 653	Pavement Wearing Surfaces
CPE 654	Asphalt Mix Design
CPE 655	Pavement Maintenance & Rehabilitation
CPE 656	Industrial & Heavy Duty Pavements
CPE 657	Pavement Management
CPE 658	In Situ Stabilisation
CPE 659	Road Asset Management
CPE 660	Rigid Pavement Construction
CPE 66X	Fundamentals of Road Construction (draft)
CPE 662	Managing Pavement Environment (draft)

Each year at least one additional pavements-orientated unit is being added to the list.

The courses recognise and build on the experience gained in the pavement industry by students and enhance their theoretical knowledge without a long term commitment, or need to 'qualify' for acceptance, which is required for those entering the Masters courses.

Any unit(s) can be undertaken independently, without enrolment into a Masters program. This allows for tailored and rapid updating of knowledge without a long term commitment, or need to 'qualify' for acceptance, which is required for those entering the Masters courses.

2.1 Course Operation

The requirement for entry to the Master of Engineering in Pavements is a four-year Bachelor degree in a pavement engineering related discipline or an equivalent qualification. Applicants for the Master of Technology in Pavements must hold a Bachelor degree in a pavement engineering related discipline or an equivalent qualification. Entry with a three-year Bachelor degree is restricted to those with at least three years relevant pavement industry experience. Anyone with a three-year Bachelor degree and a pavement engineering related postgraduate qualification or a four-year Bachelor degree may be granted advanced standing. If an applicant does not meet these entry requirements they may still apply to be considered through special entry provisions which consider industry experience and prior learning.

When candidates enrol in the ICPEE distance learning program (see Section 3) they are sent a course package for each of the units they are studying. All packages contain a study module which provides an outline of the unit syllabus, contact details for the tutor and a study schedule including assignments and sample examination questions. The package also contains printed course materials in a study guide presented as a number of topics each with relevant 'readings'. The latter consist of useful extracts from the literature chosen to support the written material. In some units the course package contains computer software associated with the assignment work for those units. The assignments and the written study material emphasise the practical side of pavement engineering and students are encouraged to apply what they learn from the course in their day to day activities in the workplace. The practical emphasis in the program is achieved by engaging experts from the pavement industry and university staff with industry experience to prepare the study material. Furthermore, the unit syllabuses evolve from discussions with industry groups and each unit is reviewed by industry prior to being offered in the course. This 'technical' review is in addition to the 'instructional design' review which assesses the quality of study material as a distance learning package.

The end product is a comprehensive set of 'user friendly' technical notes, readings, references, case studies and assignments.

Although the study material has been prepared under the direction of the Australian and New Zealand pavement industry the contents are applicable to other countries. The fundamental processes and procedure covered by the course curriculum are universal. Candidates have studied ICPEE units in locations where the climate, available technology, materials and other variables are significantly different from Australia and New Zealand, yet they report that they are able to apply much of what they learn from the course to their 'different' working conditions. In fact many candidates move from one region to another while completing the course and again the feedback about course content is positive.

The courses are conducted totally by distance education on a semester basis; there are no requirement for participants to attend lectures. For each unit a consultant lecturer is available to answer questions and to provide other assistance

as necessary throughout the semester. Assistance can be obtained by facsimile, e-mail, mail or telephone.

Performance in a unit is assessed by a formal three-hour examination at the end of the semester. Examination venues are arranged through universities and educational centres throughout the world as well as in all parts of Australia. Two assignments must also be completed as part of the overall assessment for each unit.

3. GLOBAL OPPORTUNITIES – ESTABLISHMENT OF ICPEE

The success and standing of CPEE-Australia in such a short time, and with its student intake global in nature (from New Zealand to Ireland and South Africa to Kazakhstan), it became readily apparent that the Centre was capable of being international in its operation. The International Centre for Pavement Engineering Education (ICPEE) was therefore established in 2001 to provide a more dedicated international focus and to facilitate enhancements that would achieve worldwide advantages to 'students' and employers alike.

ICPEE serves a worldwide market for postgraduate pavement engineering education. Support and assistance from the local industry association or university could develop a 'customised distance learning program operated directly with ICPEE or it may lead to the establishment of centres equivalent to CPEE-Australia in other countries. Whatever the mode of operation, the study and assessment arrangements are likely to be the same as those successfully operating through the existing CPEE-Australia.

When fully operational ICPEE will offer a range of benefits to both local industry and partner universities. The globalisation of pavement engineering education will greatly facilitate the transfer of technology and expertise. The elusive intent of 'world's best practice' terminology, derived from the manufacturing sector, will create a real target for the pavement industry.

3.1 Benefits of International Acceptance of Industry Support for Unified Education Provisions and Qualification

Whilst industry and its major clients are likely to quickly appreciate the need for action, the universities in 'home' countries, if their involvement is sought, will find it more difficult to act quickly and be proactive in adjusting to the mechanism proposed. However, Universities can have an important role to play if they so choose and an option exists whereby a university can choose an involvement that will generate additional income and gain added recognition (both locally and internationally). Income-conscious universities with limited resources to develop new programs will find the proposal offers an attractive solution.

It is intended that those graduating from ICPEE, or via a 'local' university endorsed by ICPEE, will gain an international standing that provides them and their employer (or prospective employer), with a guarantee that the person has attained a minimum, and on a worldwide basis, consistent level of knowledge in respect of pavement engineering.

A significant aspect of an ICPEE qualification is that the pavement industry and its clients will have determined what are the most appropriate subjects/topics making up the content of the qualification awarded. Hence the courses on offer will continually reflect what the 'market' seeks and will always be relevant to industry needs. Nevertheless, the highest academic standards will be maintained by ensuring that programs are accredited by universities throughout the world.

A major incentive for 'students' and employers alike is that the undertaking of an ICPEE course is a guarantee that the 'student' will have studied up-to-date industry-nominated material with access to tutors who have significant standing in the industry itself. In addition, they will be provided with a regular ongoing update of their knowledge resulting from any changes in practice, innovation or standards and quality requirements.

This continuous education will be achieved via ICPEE's commitment to regularly conduct (i.e. at least every four years), a total worldwide review of unit content in addition to interim amendments where innovations or practical experience provides for potential enhancements to previously espoused knowledge. This will be communicated to all registered students via technical notes emanating from distinguished/reliable sources at the time of adoption.

4. CONCLUSION

A strong commitment by industry and Government to CPEE-Australia has seen the rapid development and acceptance of a Master of Technology in Pavements and Master of Engineering in Pavements. These uniquely specialised, highly relevant technical programs are now producing professional engineers with expertise in pavements well beyond past outcomes. Industry worldwide can benefit from this in the future if it recognises the need to be proactive and acts with initiative before it is too late.

In the future, at a local level (i.e. country) or internationally, ICPEE will also increase interaction with the universities to ensure research in pavements, particularly flexible pavements, matches industry requirements.

The establishment of ICPEE in 2001 provides pavement engineers, no matter where they work, the opportunity to benefit from the success of CPEE-Australia. Distance learning study units from the existing joint CPEE/Latrobe University postgraduate programs forms the basis of programs for other countries. The successful Australian CPEE model will be used, with suitable modifications, to suit the host countries' circumstances.

ICPEE will help produce graduates with core skills and knowledge applicable to the pavement industry worldwide. More importantly it enables the continuous up-grading of the engineer's knowledge by provision of relevant information in the years well after the engineer formally completes the course.

Hence pavement engineers can have an on-going education for all the years they deem it appropriate to remain at the forefront of technical development in that particular subject/field. This unique and innovative intent will provide substantial benefit to the individual and employer alike and overcome the lack of currency of learning so often encountered in university courses. The pavement industry and professional pavement engineers will appreciate and gain considerably from the benefits of a unique innovative program built on many years of relevant practical experience.

TECHNICAL NOTE

The Measurement and Management of Horizontal Stresses Resulting from Heavy Vehicle Movements

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Austroads is currently funding a research project to better define the interactions between heavy vehicles and the pavement surface and to optimise the surfacing selection process. The project is approaching this problem from two perspectives. The first seeks laboratory and field information on the performance of various surfacing types in terms of their resistance to the effects of horizontal stresses while the second seeks information on the extent of vehicle-pavement stresses from turning, braking and accelerating vehicles.

Factors that contribute to these horizontal stresses are:
- wheel load, tyre type and operating conditions,
- coefficient of friction between the pavement surface and the tyre rubber, and
- the strain at the tyre pavement interface imposed by the geometry of the movement of the wheel.

In each of these geometries, a limiting force and thus stress results from tyre slippage (skidding). Braking sometimes leads to slippage, acceleration rarely results in slippage and turning (for a multi-axle assembly) always results in slippage where a reduction in the turning circle exceeds the capacity of the tyre tread and side-wall compliance to accommodate the developed strain.

BRAKING

Fortunately, the braking stresses developed by heavy vehicles are generally proportioned across all wheels (assuming equal tyre pressure, load distribution and mechanical braking efficiency). The exception to this will be the application of engine braking (including compressive assistance systems) where the braking benefit is limited to the driven axles.

TRACTION – ACCELERATION

In contrast with the stresses due to vehicle braking, the stresses generated by an accelerating vehicle are limited to the driven axles. For a conventional tractor with two driven axles, the maximum stress developed by these wheels will generally be in proportion to the maximum torque available from the engine. As vehicles become larger, the power and torque required from the engine increases. Fortunately, the mechanical strength of gearboxes and the drive train in general have not kept pace with the increase in available engine power and have contributed to the development of various power management schemes that effectively limit the power available during the critical initial acceleration from a stationary position.

TURNING OPERATIONS

Turning vehicles can present the most demanding horizontal stresses to the pavement surfacing. In contrast with the longitudinal braking and acceleration related stresses, turning movements can generate lateral forces dependent on the geometry of the vehicle and its turning radius. These stresses are often associated with slow vehicle operations and are not limited by the power of the system.

Two sources of lateral pavement stress can be identified:

1. The steering wheels for a conventional vehicle (undriven steering wheels) provide the vehicle turning moment though the forward action of the rear driven wheels.

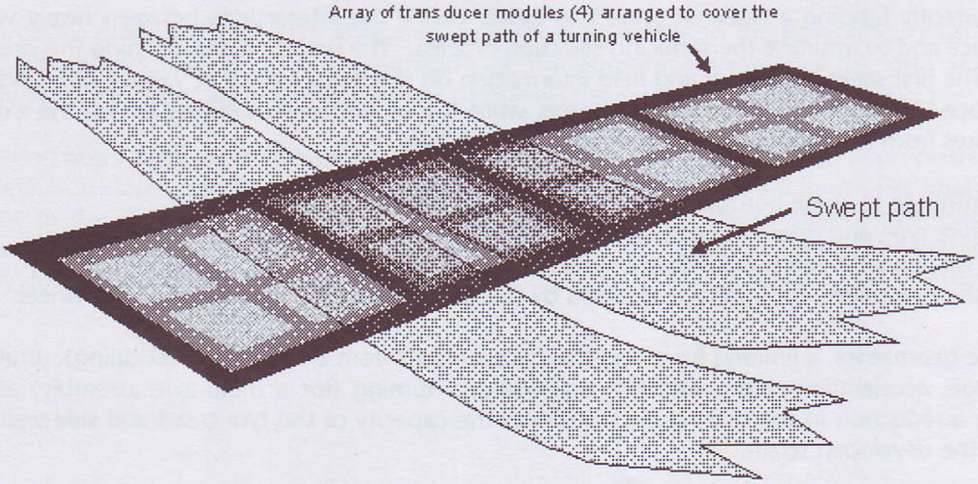
   This contrasts with front wheel drive and all-wheel drive vehicles where the motivation for the turning action is developed within the steering wheels and can result in a reduced horizontal stress on the pavement.

2. Multiple axles in both the tractor and the trailer present a significant potential stress to the pavement when the turning radius of the vehicle is below a critical value. These movements are normally undertaken at low speeds and can include simple turning movements at intersections.

   Since the skid resistance of the surfacing makes a significant contribution to the magnitude of these transverse forces, where the surface is free of contaminants and loose material, high levels of friction are experienced by tyre rubber. It should also be noted that the highest level of friction is developed for dry surfaces.

To provide data on the forces developed under these turning conditions, a transducer has been developed with a capacity to provide the levels of friction characteristic of the most demanding situations. The transducer provides an

output in the longitudinal and in the transverse directions allowing complex stress patterns to be recorded (schematic shown below). The collected data will be used to assist with the validation of vehicle tyre-pavement surface interaction models and simulations. These models will provide data on the contributions of future performance based standards (PBS) vehicles to horizontal pavement stresses.



Four modules arranged to monitor the wide swept path of a dual tyre assembly

LABORATORY STUDIES

Test methods capable of measuring surfacing performance related properties in the laboratory and in the field have been identified and these will provide a measure of the capacity of candidate surfacings to resist vehicle-initiated horizontal stresses.

An example of the proposed test methods is based on the standard British wheel-tracking apparatus. Normally used to assess asphalt mixtures for deformation at high service temperatures, the apparatus has been modified to present the trafficking wheel at an angle to the direction of travel. This configuration provides a lateral force to the laboratory-prepared specimen allowing its sensitivity to transverse stresses to be determined.

NEW ARRB GROUP

The *Australian Road Research* Board was first incorporated as a grant-funded public company in 1965. In 1995 the name was changed to *ARRB Transport Research Ltd* to reflect a change in focus from a grant-funding base to a more commercial organisation, and to extend the business base into a wider client group.

Now, 10 years on, a new agreement has been reached between Austroads and ARRB which sees Austroads funding a focussed body of research which will concentrate on sustaining critical expertise in Australia and allow ARRB to invest in staff and laboratory equipment and build research expertise for the future.

To accommodate this change in focus three independent divisions have been established. One of these is a '*research institute*' *(ARRB Research)*, with the financial goal of achieving a sustainable break-even position and the 'price' of the research work will reflect this. The other two divisions, *ARRB Technology* and *ARRB Consulting*, will operate as commercial entities.

ARRB Group was chosen as the new name to emphasise the collection of divisions which make up the whole organisation, while retaining the recognisability of the name ARRB.

Under the new research agreement, Austroads will fund a rolling three year research program at *ARRB Research*. Research will be undertaken in the areas of *bituminous surfacings*, *pavement technology*, *asset management*, and *engineering safety*, all of which were identified as being crucial to the management of the Australasian road network.

In the first year of operation (2004/2005), Austroads has commissioned *ARRB Research* to undertake the following 12 projects:

Bituminous surfacings:

- Quantifying the stresses at the tyre/surface interface and the resulting performance impacts
- Improved sprayed sealing operations – procedures and guidelines
- Maximising the benefits from polymer modified binders
- Using overseas bitumen

Pavement technology:

- Influence of vertical loading on the performance of unbound and cemented materials
- Delivering better quality asphalt

Asset management:

- Standardised measurement of road condition
- Intervention standards and cost models
- Maintenance techniques to manage social and environmental impacts
- Long-term performance monitoring to develop consistent performance models
- Establish network performance profiles, identify under-performing pavements and establish contributory causes

Engineering safety:

- Road risk assessment

The outputs of many of the projects should be of interest to members and a summary of the findings will be published in future editions of the Journal.